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(54) Name of Invention: Dry-etching Method

(57) Summary

**Purpose:** To etch SiO<sub>2</sub> layers while sustaining a high selectivity ratio toward Si<sub>3</sub>N<sub>4</sub> layers.

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**Makeup:** With a dry-etching device that can create high-density plasma in which the ion density is  $10^{11}$  ions/cm<sup>3</sup> or more, one uses a fluorocarbon (FC) gas represented by the general formula  $C_x F_y$  (with  $y$  equal to or less than  $x + 2$ ). As the dissociation proceeds to a high degree in the gases in such high-density plasmas as ECR plasma and the like,  $CF^+$  is yielded with good efficiency from  $C_6F_6$  gas that could only deposit carbon-system polymers with the usual RF plasmas, making it possible to do high-speed etching of insulative film 4 between silicon dioxide layers. On the other hand, since the above-noted FC gas has a large C/F ratio, it does not produce excessive  $F^+$ , and high selectivity is obtained toward underlying  $Si_3N_4$  film 3. Conversely, when etching a silicon dioxide layer with the  $Si_3N_4$  layer as a mask, high mask selectivity is obtained.

### **Scope of Patent Application**

**Application Item 1:** In an etching device capable of producing plasmas of a high-density of  $10^{11}$  ions/cm<sup>3</sup> or more, a dry-etching method characterized by causing the production of etching-gas plasmas that are mainly fluorocarbon chemicals expressed in the general formula  $C_x F_y$  (with  $x$  and  $y$  being natural numbers satisfying the relation of  $y$  being equal to or less than  $x + 2$ ) and characterized by selectively etching the layer of silicon oxide-system material formed on a layer of silicon nitride system material.

**Application Item 2:** In an etching device capable of producing plasmas of a high-density of  $10^{11}$  ions/cm<sup>3</sup> or more, a dry-etching method characterized by producing an etching-gas plasma in which a fluorocarbon system compound expressed by the general formula  $C_x F_y$  (with  $x$  and  $y$  being natural numbers satisfying the relation of  $y$  being equal to or less than  $x + 2$ ) has as its main component the fluorocarbon compound, and characterized by etching layers of silicon oxide material while using as a mask a layer of silicon nitride material patterned in a prescribed shape.

**Application Item 3:** The dry-etching method described in either of Application Items 1 or 2, which is characterized by the above-noted fluorocarbon system compound being a hexafluorocarbon.

### **Detailed Explanation of Invention**

**0001 Field for Commercial Utilization:** This invention relates to dry-etching methods applied in such fields as the manufacture of semiconductor devices, and in particular bears on a method of etching while securing a high selectivity rate between layers of silicon nitride-system materials and silicon oxide-system materials.

**0002 Usual Technology:** For the component materials of interlayer insulating films in silicon devices, silicon compound layers are generally used. Among those the most widely used is silicon oxide ( $SiO_x$ , typically with  $x = 2$ ). At this time, the dry etching of  $SiO_x$  interlayer insulating film is a technique that has matured for application mostly to 64K DRAM production and even for mass-production lines.

0003 The above-noted dry etching has from the outset used as its etching gas mainly components of such fluorocarbon compounds as  $\text{CHF}_3$  and  $\text{CF}_4/\text{H}_2$ ,  $\text{CF}_4/\text{O}_2$  or  $\text{C}_2\text{F}_6/\text{CHF}_3$  combinations. This is due to such reasons as (a) carbon atoms contained in fluorocarbon compounds produce a strong bonding energy between atoms on the surface of the  $\text{SiO}_x$  layer and work to break or weaken the Si-O bond; (b) they can produce  $\text{CF}_x^+$  (typically,  $x = 3$ ) the main source for etching  $\text{SiO}_2$  layers; and (c) by controlling the C/F ratios (the ratio of C and F atoms) in the etching-reaction system it can optimize the amount of carbon polymer deposited and attain high selectivity toward resist masks and underlying layers.

0004 What I here call the underlying layers indicates mainly the silicon substrate, polysilicon, polycide [sic] film, etc.

0005 Silicon nitride ( $\text{Si}_x\text{N}_y$ , especially when  $x=3$  and  $y=4$ ) also is an insulating-film substance applied in silicon devices. With dry etching of  $\text{Si}_x\text{N}_y$  layers, too, basically the same gas components are applied as in the etching of  $\text{SiO}_x$  layers. However, whereas  $\text{SiO}_x$  layers are etched mainly by the mechanism of ion-assist reactions,  $\text{Si}_x\text{N}_y$  layers are etched based on the radical-reaction mechanism making  $\text{F}^+$  the main source of etching; and the etching rate are also is faster than with silicon dioxide layers. This can be predicted to some degree by the fact that the bonding energy relationships between atoms is Si-F (553kcal/mole) > Si-O bond (465 kJ/mole) > Si-N bond (440kcal/mole).

0006 Some differences emerge from the calculating methods in the atomic bonding energy; but here I am citing data recorded in R.C. Weast's "Handbook of Chemistry and Physics," 69<sup>th</sup> ed. (1988), CRC Press, California.

0007 Now, among the manufacturing processes for silicon devices there are several requiring high-selectivity etching between  $\text{SiO}_x$  and  $\text{Si}_x\text{N}_y$  layers. For instance, the etching of an  $\text{Si}_x\text{N}_y$  layer on top of an  $\text{SiO}_x$  layer is done under the LOCOS method in patterning to define element-separation regions. Under current conditions, where pad oxide films ( $\text{SiO}_2$ ) for holding Barr's peak [Assumed from Japanese phonetics, Could also be buzz peak. -- Translator] lengths to a minimum are made as thin films, the above-noted etching is a process requiring particularly high selectivity toward the underlying  $\text{SiO}_x$  layer.

0008 Also, in recent years, as devices have become tinier and more complex, there are increasingly cases in which  $\text{Si}_x\text{N}_y$  layers are formed as etching-blocker layers in a variety of places to prevent etching damage, thus giving rise the need also for highly selective etching of  $\text{SiO}_x$  layers on  $\text{Si}_x\text{N}_y$  layers. For example, to reduce substrate damage when over-etching a thin  $\text{Si}_x\text{N}_y$  layer is interposed on the substrate surface, or a gate-insulating film having a so-called ONO structure ( $\text{SiO}_x$  layer/  $\text{Si}_x\text{N}_y/\text{SiO}_x$  layer) is formed. Or, in cases when an  $\text{Si}_x\text{N}_y$  layer is laminated on the surface of a gate electrode, the etching of an  $\text{SiO}_x$  layer done on this must be reliably halted.

0009 And yet, to do highly selective etching between laminated layers of differing substances it generally is desirable to have some degree of difference in the atomic-bonding energy of both layers. But, with  $\text{SiO}_x$  and  $\text{Si}_x\text{N}_y$  layers the atomic bonding

energies of the Si-O and Si-N are comparatively close, making it intrinsically difficult to do highly selective etching between the two.

**0010** Various places have for some time been pushing the development of techniques for making selective etching possible.

**0011** We have several reports on techniques for etching  $\text{Si}_x\text{N}_y$  layers on  $\text{SiO}_x$  layers. For instance, this inventor reported in Patent Report Release Sho. 61-142744 a technique for using etching gas that combines  $\text{CO}_2$  at 30~70% mole ratio with such gases as  $\text{CH}_2\text{F}_2$  in which the C/F ratio (ratio of carbon and fluorine atoms in a molecule) is small. Gases with small C/F ratios can yield  $\text{CF}_x^+$  (especially when  $x=3$ ), the etching element for  $\text{SiO}_x$  layers only by re-combination of the  $\text{F}^+$ ; but when a large quantity of  $\text{CO}^+$  is supplied into this system and it captures and removes  $\text{F}^+$  in the form of  $\text{COF}$ , the amount of  $\text{CF}_x^+$  produced is reduced and the etching rate of the  $\text{SiO}_2$  layer declines. On the other hand,  $\text{Si}_x\text{N}_y$  can be etched with  $\text{F}^+$  as the main etching element, so that the etching rate scarcely changes even if the  $\text{CF}_x^+$  declines due to a large amount of  $\text{CO}_2$  introduced. In this way, selectivity can be obtained between both layers.

**0012** Also, in "Proceedings of Symposium on Dry Process" 88:7, pp. 86-94 (1987) a technique is reported for supplying  $\text{NF}_3$  and  $\text{Cl}_2$  into a chemical dry-etching device and using  $\text{FCl}$  formed in that atmosphere by a microwave discharge to etch an  $\text{Si}_x\text{N}_y$  layer on  $\text{SiO}_x$ . Whereas the Si-O bond includes 55% ion bonding, for the Si-N bond it is 30%, making the common [shared] bonding ratio high. I.e., the nature of the chemical bond in the  $\text{Si}_x\text{N}_y$  layer is close to that of the chemical bond (common bond) in monocrystalline silicon, and such radicals as the  $\text{F}^+$  and  $\text{Cl}^+$  produced by dissociation from the  $\text{FCl}$  do the etching. However, since  $\text{SiO}_x$  layers are scarcely etched by these radicals, highly selective etching becomes possible.

**0013 Issues the Invention Seeks to Resolve:** As discussed above, a number of techniques for selective etching of  $\text{Si}_x\text{N}_y$  layers on  $\text{SiO}_x$  layers have been reported. This is natural, in a sense, when one considers the etching rate of both layers. That is because with a process that relies mainly on radical reactions, if the  $\text{SiO}_x$  layer is exposed during the etching, the etching rate naturally slows down.

**0014** However, there are problems also with the usual technology. For instance, in the above-discussed process using  $\text{FCl}$ , the anisotropic processing is essentially difficult because of using the radical reactions.

**0015** On the other hand, because securing selectivity is difficult as compared to the reverse case, we have few examples of any reports. That is because even though  $\text{SiO}_x$  layers are etched by mechanisms making ion-assisted reactions primary, radicals are inevitably created in that reaction system; and at the point when  $\text{Si}_x\text{N}_y$  becomes exposed these radicals raise the etching rate of the underlying layer.

**0016** Quite recently, techniques are being proposed that achieve this using a high-density plasma that reduces the amount of radicals produced by using a new plasma source. For

instance, in "Proceedings of the 43<sup>rd</sup> Symposium on Semiconductors and Integrated Circuit Technology," p. 54 (1992), there is introduced an example of a process that uses  $C_2F_6$  (hexafluoroethane) to etch an  $SiO_2$  layer formed by the TEOS-CVD method on an  $Si_3N_4$  layer formed by the LPCVD method using an induction-coupled plasma of  $C_2H_6$  gas. In high-density plasma, gas dissociation proceeds at a high rate, so that it is thought that the  $C_2F_6$  is nearly all broken down into small  $CF^+$  ions and that this contributes to the etching. Also, carbon atoms in the low C/F ratio fluorocarbon-system polymer deposited at this time couple more easily to the atoms in the  $SiO_x$  than do the nitrogen atoms in the  $Si_xN_y$ , so that they are removed at the surface of the  $SiO_x$  layer but deposit on the  $Si_xN_y$ . This is thought to be the mechanism that attains selectivity.

**0017** This technique is rather promising, but falls short in not readily achieving stable selectivity. For example, the selectivity ratio in the above-discussed process is reported to be very large on the flat areas, but 20 or more in the corners. The scatter of such selectivity on the surfaces is considered to be due to the contribution of the  $F^+$  produced as a result of  $C_2F_6$  dissociation proceeding quickly. So, this invention has the goal of providing a method of dry-etching  $SiO_x$  layers that can secure a stable high selectivity ratio for  $Si_xN_y$  layers.

**0018 Means to Resolve the Issue:** This invention's dry-etching method is proposed after reflecting on the above-described goal and is one which, in an etching device capable of creating a plasma with an ion density of  $10^{11}$  ions/cm<sup>3</sup> or more, selectively etches  $SiO_x$ -system substance layers formed on  $Si_xN_y$ -system substance layers by creating etching-gas plasmas that are mainly fluorocarbon-system compounds expressed by the general formula  $C_xF_y$  (with x and y being natural numbers and satisfying the relationship of y being equal to or less than x+2).

**0019** What I here call high-density plasma is a plasma made by some means or another to increase the frequency of collisions between electrons and atoms compared to the usual type of plasma. What I mean by the usual type of plasma is that, for instance, which is excited by impressing RF power between parallel plate electrodes to cause a glow discharge or by supplying microwave to a waveguide. By contrast, high-density plasma is that which promotes a high degree of gas dissociation by using electron cyclotron resonance based, for instance, on the interaction of microwave fields and magnetic fields, or by using microwave propagation modes in a magnetic field, called a whistler mode, thus achieving high ion density.

**0020** As concrete examples of plasmas having ion densities of  $10^{11}$  ions/cm<sup>3</sup> or more, one knows of ECR plasma, helicon-wave plasma, ICP (inductively coupled plasma, TCP (transformer coupled plasma), holo-anode [Assumed from Japanese phonetics.--Translator] type plasma, helical resonator plasma, etc.

**0021** Also, as is evident from the general formula for the above-noted fluorocarbon-system compounds, they are unsaturated compounds. Carbon frames of either chain or annular form can meet this requisite. However, if the number of carbons is somewhat greater and in chain form, it will necessarily have to have structure of multiple over-

lapping bonds or multiple conjugated bonds, condensed rings, multiple rings, spiro-rings or ring collections.

**0022** As examples of fluorocarbon-system compounds meeting such requisites, one can cite tetrafluoro-ethylene ( $C_2F_4$ ), hexafluorobutadiene ( $C_4F_6$ ), tetrafluoro-cyclopropane ( $c-C_3F_4$ ), hexafluoro-cyclo-butane ( $c-C_4F_6$ ), hexafluorobenzene ( $C_6F_6$ ), octafluoro-cyclo-butatriene ( $c-C_7F_8$ ), octafluoro-bicyclo[2.2.1]-heptadien ( $C_7F_8$ ), etc.

**0023** This invention also is one that, in an etching device capable of producing plasmas of a high-density of  $10^{11}$  ions/cm<sup>3</sup> or more, produces an etching-gas plasma in which a fluorocarbon system compound expressed by the general formula  $C_x F_y$  (with x and y being natural numbers satisfying the relation of y being equal to or less than x + 2) has as its main component the fluorocarbon compound and does etching of layers of silicon oxide material while using as a mask a layer of silicon nitride material patterned in a prescribed shape.

**0024** This invention furthermore is one that uses hexafluorobenzene for its above-noted fluorocarbon-system compound.

**0025 Effects:** When one forms a high-density plasma with an ion density of  $10^{11}$  ions/cm<sup>3</sup> or more using an etching gas that is mainly a fluorocarbon-system compound, even under low pressure in comparison to usual RF plasmas, the fluorocarbon-system compound's dissociation proceeds; and large amounts of  $CF_x^+$  (but mostly x=1) are produced with good efficiency. While being assisted by this richness of ions, the silicon-compound layer is being etched at a practicable rate.

**0026** However, if large amounts of  $F^+$  are produced along with large amounts of  $CF_x^+$ , that will cause selectivity toward the  $Si_xN_y$  layer to drop. So, to keep excessive  $F^+$  from forming in the plasma, in this invention one uses compounds with less C atoms than F atoms—i.e., fluorocarbon compounds with molecules whose C/F ratio is large as the main components of the etching gas. In the case of this invention, the number of F atoms y will at most be twice the number of C atoms x, so that if—to simplify things—one thinks of x number of  $CF^+$  being produced from one molecule, a maximum of two  $F^+$  will be produced.

**0027** With this invention, since one uses such fluorocarbon-system compounds to etch  $SiO_x$ -system layers on  $Si_xN_y$  layers, there is no risk of the exposed surface of the  $Si_xN_y$  layer being exposed to high densities of  $F^+$ . So, that means that high underlying-layer selectivity is achieved with respect to the underlying  $Si_xN_y$  layer. This principle holds exactly true also when, conversely, one is using an  $Si_xN_y$  layer patterned in a prescribed shape as the etching mask for its underlying  $SiO_x$  layer, achieving high mask selectivity.

**0028** Now, I plan with this invention especially to use hexafluorobenzene ( $C_6F_6$ ) as the above-noted fluorocarbon compound; because this is stable, easy to handle, has a large C/F ratio of 1, etc. There have earlier been tests on using  $C_6F_6$  in etching layers of  $SiO_x$ -system material. But, as described for instance in Patent Report Hei.1-60938, since it

forms large amounts of  $\text{CF}_3^+$  and  $\text{CF}_2^+$  when used alone and interferes with the progress of the etching reaction, it has not been practical. In the above-noted Report, because of this interference with carbon-system polymers, one resolves the problem by using a gas in which  $\text{CF}_4$  is admixed 1:1 with the  $\text{C}_6\text{F}_6$ .

**0029** However, because with this invention the  $\text{C}_6\text{F}_6$  is dissociated into  $\text{CF}^+$  in the high-density plasma, there is no fear of carbon-system polymers accumulating excessively. Moreover, even if the bonds between carbon & carbon should all be broken and six  $\text{CF}^+$  were produced from each molecule, in theory not a single  $\text{F}^+$  would be produced, and high selectivity would obtain with the  $\text{Si}_x\text{N}_y$ -system layer. Also, from the aspects of stability, control, etc., one can call the point that highly selective etching is realized with a single-gas system an advantage of this invention.

**0030 Application Examples:** Below, I will explain concrete examples of applying this invention.

**0031 Application Example 1:** This application example is a case of using magnetic-field microwave plasma etching with  $\text{C}_6\text{F}_6$  gas to open a contact hole by etching an  $\text{SiO}_2$  interlayer insulating film having an underlying  $\text{Si}_3\text{N}_4$  film. I will explain this process while referring to Figure 1.

**0032** As shown in Figure 1(a), one first forms  $\text{Si}_3\text{N}_4$  under-film 3 10nm thick, for instance by PCVD, on silicon substrate 1 on which impurity diffusion region 2 has been formed in advance, and then uses CVD at normal pressure to form  $\text{SiO}_2$  interlayer-insulating film 4 1000nm thick. One further applies onto above-noted  $\text{SiO}_2$  interlayer insulating film 4 the Novolak [Assumed from Japanese phonetics.-- Translator] positive photo resist TSMR-V3 (commercial name, from Tokyo Oyo Kagaku Co.) and uses i-beam lithography and alkali development to form resist mask 5 having 0.35 $\mu\text{m}$  diameter opening 6.

**0033** This wafer is set on the wafer-mounting electrode of a magnetic-field microwave plasma etching device and, for instance under the conditions listed below, has its  $\text{SiO}_2$  interlayer insulating film 4 etched.

$\text{C}_6\text{F}_6$ flow rate:	20 SCCM
Gas pressure:	0.65 Pa
Microwave power:	1500W (2.45GHz)
RF bias power:	200W (800 kHz)
Wafer-mount temp.	20° C

**0034** Here, the  $\text{C}_6\text{F}_6$  dissociation proceeds by applying high microwave power and doing an ECR discharge, creating a high-density plasma on the order of an ion density of  $10^{11}$  ions/ $\text{cm}^3$ . In the above-noted etching process the etching of  $\text{SiO}_2$  interlayer insulating film 4 proceeds at a high rate due to the large amount of  $\text{CF}^+$  produced in this high-density plasma. Also, even at the point when underlying  $\text{Si}_3\text{N}_4$  film 3 is exposed, high

selectivity toward this film is attained because excessive  $F^+$  is not produced in the plasma. Of course, the selectivity also is good for resist mask 5.

**0035** This etching resulted in contact hole 7 being formed with an anisotropic shape as shown in Figure 1(b) without corroding  $Si_xN_y$  under-film 3 exposed on its under surface.

**0036** In this etching process, some accumulation of carbon-system polymer, not illustrated, can be seen. This polymer is removed by the combustion effect of oxygen atoms sputtered out from the etched region of  $SiO_2$  interlayer insulating film 4; but this contributes to protecting the surface of resist mask 5, the sidewalls of contact hole 7 and the exposed surface of  $Si_3N_4$  under-film 3.

**0037** In any case, however, it does not obstruct the etching progress by accumulating large amounts of carbon-system polymer as in the usual case.

**0038** Next, the wafer is transferred to a plasma ashing device, and oxygen-plasma ashing is done under the usual conditions, removing resist mask 5 as shown in Figure 1(c). At this time the carbon-system polymer, not shown, that contributed to protecting surfaces and sidewalls is simultaneously removed.

**0039** Finally, the wafer is immersed in hot phosphoric acid and under-film  $Si_3N_4$  exposed at the bottom of contact hole 4a is dissolved and removed, as Figure (d) shows. Through the above-noted processes one can form contact hole 7, with a good anisotropic shape without damaging impurity diffusion region 2 or causing particle contamination.

**0040 Application Example 2:** This application example is one done by using an ICP etching device and  $C_6F_6$  gas to etch  $SiO_2$  interlayer insulating film in the self-aligning contact process for forming the connections of a memory node and the gate electrode of a TFT for the negative charge of an SRAM. I will explain this process while referring to Figure 2.

**0041** Figure 2(a) shows the makeup of the wafer used as an etching sample in this application example. This wafer is one on which gate oxide film 13 is formed on silicon substrate 11 by surface oxidation, and on this are patterned two gate electrodes 16 of the driver transistor and  $Si_3N_4$  etching-stopper layer 17 for protecting these gate electrodes 15 from a later etching process. The above-noted gate electrodes 16 consist—in order from their lowest layer—of polysilicon layer 14 and tungsten silicide ( $Wsi_x$ ) layer 15 laminated with a tungsten polycide film. On both sides of gate electrodes 16, sidewalls 18 of  $SiO_2$  are formed by an etching process; and impurity diffusion region 12 is formed with an LDD structure in silicon substrate 11 by two ion injections using above-described gate electrodes 16 and sidewalls 18 as a mask.

**0042**  $SiO_2$  interlayer insulating film 19 is deposited, for instance by the CVD method, over the entire surface of this wafer, and resist mask 20 is formed in a prescribed pattern on top of that. This resist mask 20 covers part of both gate electrodes 16 and has an



opening 21 at their middle region. Inside this opening 21, SiO<sub>2</sub> interlayer insulating film 19 is etched as far as the impurity diffusion region to form a contact hole.

**0043** The above-noted wafer is set in an ICP etching device and, as one case, SiO<sub>2</sub> interlayer insulating film 19 is etched under the following conditions:

C <sub>6</sub> F <sub>6</sub> flow rate:	20 SCCM
Gas pressure:	0.65 Pa
RF source power:	2500W (2 kHz)
RF bias power:	50W (1.5 MHz)
Wafer-mount temp.	0° C

In this process the etching proceeds on SiO<sub>2</sub> interlayer insulating film 19 with a CF<sup>+</sup> etching agent from high-density plasma on the order of 10<sup>11</sup> ions/cm<sup>3</sup> created in an ICP etching device. As shown in Figure 2(b), the result is that SiO<sub>2</sub> interlayer insulating film 19 and part of gate SiO<sub>2</sub> film 13 are removed and contact hole 22 is completed, while still another sidewall 19a is formed on the previously formed sidewall 18.

**0044** Now, during this etching Si<sub>3</sub>N<sub>4</sub> etching-stopper layer 17 becomes exposed; but—as already explained for Application Example 1—the dissociation of the C<sub>6</sub>F<sub>6</sub> proceeds at a high rate and the amount of F<sup>+</sup> produced in the plasma is small, so that an adequately large selectivity is sustained toward Si<sub>3</sub>N<sub>4</sub> etching-blocker layer 17. Hence, one is able to avoid damage to gate electrodes 16 even when etching the high steps of SiO<sub>2</sub> interlayer insulating film 19.

**0045 Comparative Example:** Here, I will explain, as an example for comparison with Application Example 2, a case of using the ICP etching device and C<sub>6</sub>F<sub>6</sub> gas to form self-aligning contacts of the same SRAM. First, one sets the same kind of wafer as that shown in Figure 2(a) into the ICP etching device and etches SiO<sub>2</sub> interlayer insulating film 19 under the following conditions, as one example:

**0046**

C <sub>6</sub> F <sub>6</sub> flow rate:	20 SCCM
Gas pressure:	0.65 Pa
RF source power:	2500W (2 kHz)
RF bias power:	50W (1.8 MHz)
Wafer-mount temp.	0° C

**0047** In this process, CF<sup>+</sup> of course is created through high-efficiency dissociation, while F<sup>+</sup> is produced at the same time, reducing the selectivity toward Si<sub>3</sub>N<sub>4</sub> etching-stopper layer 17. As shown in Figure 3, the result is that gate electrodes 16 under the corroded Si<sub>3</sub>N<sub>4</sub> etching-stopper layer 17b also are partially corroded, and the cross-sectional shapes of sidewalls 18b and 19b each deteriorated.

**0048** In the foregoing I have explained this invention on the basis of two application examples; but this invention is not limited to these examples. For example, with the

above-discussed application examples I took up the ICP device and ECR plasma as the high-density plasma; but one might also use any plasma such as a halo-anode type plasma with  $10^{12}$  ions/cm<sup>3</sup>, a helicon-wave plasma or TCP that have been reported with an ion density on the order of  $10^{12}$ ~ $10^{13}$  ions/cm<sup>3</sup>.

**0049** Using as the etching gas the fluorocarbon-system compound  $C_xF_y$  also is not limited to the above-discussed  $C_6F_6$ , but could consist of any compound that meets the condition of  $y$  being equal to or less than  $x + 2$ , also being capable of existing stably and also being easily introduced into the etching chamber in a gaseous state.

**0050** Again, as other processing examples that may be applied there are such ones as the etch-back of an  $SiO_2$  interlayer insulating film on a triple-layer gate insulating film having an ONO structure ( $(SiO_x/Si_xN_y/SiO_x)$ ). This is a process for forming sidewalls on the side surfaces of gate electrodes, and in such case the etch-back can be halted with high selectivity on  $Si_3N_4$  film between the gate insulating films.

**0051** Needless to say, the etching conditions and etching devices can be appropriately altered.

**0052 Effectiveness of Invention:** As is clear from the above explanations, high C/F-ratio fluorocarbon compounds that in the past could not be used because they produced too much carbon-system polymer can, with the dry-etching method of this invention, be dissociated to a high degree in high-density plasmas by using them as the main component of the etching gas. Moreover, such fluorocarbon-system compounds do not excessively produce  $F^+$  under the conditions for discharge dissociation so that it becomes possible to achieve selective etching between the  $SiO_2$  material layers and  $Si_xN_y$  material layers.

**0053** Consequently, this invention is applicable to the manufacture of semiconductor devices that are highly integrated and high function, designed on the basis of minute design rules, and so has a very great value in their industry.

### Simple Explanation of Figures

**Figure 1** is a schematic cross-sectional diagram showing in processing order an example of applying this invention to contact-hole processing. Shown respectively are (a) the situation where a resist mask has been formed on an  $SiO_2$  interlayer insulating film, (b) the situation where the etching of the  $SiO_2$  interlayer has stopped at the underlying  $Si_xN_y$ , (c) the situation where the resist mask has been removed by ashing, and (d) the situation where the underlying  $Si_3N_4$  film has been removed by ashing.

**Figure 2** is a schematic cross-sectional diagram showing in processing order an example of the process of applying this invention to processing a self-aligning contact. Shown respectively are (a) the situation where the  $SiO_2$  interlayer insulating film has been formed covering two gate electrodes having an  $Si_xN_y$  etching-stopper layer, and (b) the situation where a contact hole has been formed while forming sidewalls.

**Figure 3** is a schematic cross-sectional diagram showing, in a comparative example of an SRAM's self-aligning contact, the situation where selectivity toward the  $\text{Si}_x\text{N}_y$  etching-stopper layer has declined and the cross-sectional shape of the gate electrodes and sidewalls has deteriorated.

#### **Explanation of Keying Symbols**

- 1, 11 ... Silicon substrate
- 2, 12 ... Impurity diffusion region
- 3 ... Underlying  $\text{Si}_3\text{N}_4$  film
- 4, 19 ...  $\text{SiO}_2$  interlayer insulating film
- 5, 20 ... Resist mask
- 6, 21 ... Opening
- 7, 22 ... Contact hole
- 13 ... Gate oxide film
- 16 ... Gate electrode
- 17 ...  $\text{Si}_3\text{N}_4$  etching-blocker layer
- 18, 19 ... Sidewalls